Evaluating constructivist computing for education

THE AIM

This project aims to evaluate the potential of *constructivist computing* (CC) in support of education through a multiple case study involving collaborations between computing and educational specialists. Three subprojects will address the opportunities and difficulties that CC presents from the perspectives of an educational researcher, a teacher and a learner.

CC offers an alternative methodology for integrating computing technology into learning applications, quite unlike current approaches in computer science (such as object-oriented, service-oriented or user-centred development). In CC, experience and social interaction rather than technological affordances define and distinguish the roles of ‘designers’, ‘programmers’ and ‘users’, and ‘teachers’, ‘developers’ and ‘learners’. CC aspires to assist the educational community not only by offering a technical resource, but by enabling a social institution through which ever-evolving artefacts to support learning and understanding are developed collaboratively by participants with quite different motivations, levels of technical expertise and domain knowledge. In this respect, it will contribute to **inclusion**. CC also aligns computer-based modelling to domain learning in a way that promotes **productivity**, **personalisation** and **flexibility**. We plan opportunities for support and further collaboration for TRLP participants and users.

Through carrying out the research, we shall be able to assess the value of constructivist computing and its relevance and application in an educational context. The project builds on research in the Empirical Modelling (EM) group in Computer Science (CS) and the CeNTRE in the Warwick Institute of Education (WIE), and on their previous collaboration [1]. Dissemination strategies are built into the proposal, which can be seen as a step towards establishing a national centre of constructivist computing at Warwick.

THE BACKGROUND

Constructivist computing: Constructivist computing (CC) is a radical alternative conception of computing that has been developed in the Empirical Modelling project within CS at Warwick [2,3]. CC is *radical* in its contention that the very concepts of a "use" of a computer and of a "behaviour" of a program in context are socially constructed (cf. [4]). This challenges the presumption that all computing has ultimately to be accounted for in terms of primitive calculations with specific goals (as in *Turing computation*). In place of this foundation, CC substitutes principles and tools that directly address the way in which, through interaction, we interpret the immediate experience that computing technology affords. This liberates the potentially rich, open and ambiguous meanings associated with interactive computer-based artefacts that cannot be imposed by preconceived closed conventions of use. It allows CC to create part-familiar virtual artefacts with unexplored potential for interaction that can represent the elements of confusion and uncertainty characteristic of authentic learning. CC admits varieties of traditional computer use – and the associated optimisation-to-purpose – as specialisations. ‘Constructivist computing’ is a synonym for ‘Empirical Modelling’ chosen to express the intimate relation between EM, an activity that as of now is on the fringe of computer science, and the domain of social studies. Interdisciplinarity is crucial both in nurturing EM in support of learning and in evaluating its credentials as a legitimate form of constructivist activity. Particularly relevant are the links between EM and William James’s *radical empiricism* [5], and between EM and the characteristics of constructivism as set out by Latour [6].

Empirical Modelling: EM research [2] is a wide-ranging activity, directed by Beynon and Russ in computer science at Warwick, that has been largely sustained by research students and undergraduate student project work. It has led to the development of special-purpose principles and tools whose application has been the basis for over 100 refereed publications on many aspects of computing, more than 20 graduate theses, and an extensive archive of models [3]. The enabling technology for **inclusion** in the EM culture is the *construal*: an interactive model that mediates understanding of a situation in such a way that the communicator and the listener have exactly the same privileges for interaction, and each according to his or her knowledge and experience can be “programmer”, “user”, “teacher” and “learner” alike. A construal comprises counterparts of the *observables* that are as of this moment deemed relevant to expressing the situation, with particular concern for what *agents* might be present to respond to and act upon the values of these observables, taking account of how a change to the value of any one observable may – as if in one and the same action – affect the values of other observables via a *dependency* [7].

Unlike a program, a construal is to be interpreted as expressing a current state; in true constructivist spirit, it only acquires a ‘use’ or a ‘behaviour’ as and when it can be observed and exercised in some canonical fashion consistent with the situation it expresses, and the changes to the values of observables that the human interpreter deems to occur as a result of the actions of extant agents are automated to follow an appropriate pattern. The importance of construals in support of learning lies in the fact that they admit speculative interactions that may or may not bear interpretation [8].

Examples based on past work show how EM can support **productivity**, **personalisation** and **flexibility**:

Productivity in learning and empirical studies of learning: (i) Dependencies can be built up incrementally to reflect the way in which our understanding of complex situations relates to simpler forms of perception and understanding. To play noughts-and-crosses, we need to be able to perceive the winning lines, to interpret configurations of Os and Xs, to assess what is a good square to play in and to know whose turn it is. An EM model combines dependencies in layers to reflect how these various aspects of understanding interact. The model can be used as a computer program to play the game, but also to simulate forgetting whose turn it is, changing the winning lines, cheating, changing the rules – even whilst "the game" is in progress [9]. An educational researcher could use a model of this nature in empirical studies to explore stages in, or layers of, learning in the context of game-playing.

(ii) The planimeter is an instrument for measuring areas that was widely used before the computer age. Constructing EM planimeter models [3b] enabled student C to use actual instruments in the Science Museum more expertly than the curator. There was a critical point in the model making when the precise mechanics of the machine motion became clear. By tracking through the logs of the model building four years later, student H was able to reconstruct precisely the critical interaction and the reinterpretation carried out by C, and locate it to a specific date and time. The openness of the interaction in EM, and the essential negotiation of possible meaning this entails, offers better prospects for productive learning; programs by comparison may encourage mindless interaction. Analysing interaction logs also promises to give richer insight into learning than can be gained from monitoring conventional programming and use.

Personalisation in teaching: A 2D EM model of a floor plan of a room [3c] developed by student Y in 1989 was later developed by student M in 1997 into a 3D wireframe model in which physical interactions could be simulated. M's model used dependencies for mapping 3D line drawings to 2D devised by student R in 1996. In 2007, a documented sequence of interactions with M's model was presented in a computer graphics lecture to illustrate a sequence of features of projection presented in a standard graphics textbook. Students were free to imitate and elaborate on interactions of this kind in their private study of the topic. Student H subsequently blended M's model into a presentation environment – also in the form of an EM model [3d] – further enriching the scope for instructive interaction to support learning about physics, graphics and EM. This illustrates the potential for personalisation of approaches to learning, as in: book learning with some illustrative animation; learning by imitating standard interactions; open-ended potential for gifted students to extend the scope of the model (e.g. to take account of hidden lines). Note that the educational activity supported by CC *need* not itself be constructivist in spirit!

Flexibility via portability, re-use and re-interpretation: The well-known educational program JUGS was used to teach basic number theory, the quantities of liquid in two jugs representing numbers. An EM model of JUGS is expressed using observables independent of any computing platform [10a, 3e]. Adding different dependencies flexibly creates different interfaces. BBC R&D exploited related principles to support cross-platform digital broadcasting (e.g. to browsers and mobile devices); this led to the new PCF international standard [10]. In a recent model, a few dependencies were added to JUGS to link it to an EM model of a piano keyboard. The “water levels” in the jugs were then re-interpreted as fret positions on a guitar generating musical intervals displayed on the keyboard [3f].

Recent EM publications underline the potential for CC in education: these relate to constructionism and extensions of Imagine Logo [11], to lifelong learning, Latour’s constructivism and Piagetian research on child development [6], and to education for developing countries [12]. Our research on EM for learning to date has given us a partial ‘lay’ understanding of how CC might help to enhance learning outcomes. It has also provided informal circumstantial evidence that CC does indeed enhance learning outcomes in the specialised setting of computer science in higher education. To give greater authenticity to the claims we wish to make for CC and learning, the education-led initiative envisaged in this project is essential.

PROJECT OBJECTIVES AND RESEARCH QUESTIONS

The overarching research question is: *What is the potential scope and impact of CC on technology-enhanced learning?*

Three key sub-questions will frame the enquiry: *What opportunities and difficulties does CC present*

… to the educational researcher? ... to a teacher? … to a learner?

Complementary questions are: *To what extent can these … opportunities be exploited … difficulties be ameliorated … by context management … by tool elaboration?*

'Context management' here takes broad account of the educational setting (e.g. age of the learners, subject being studied, equipment being deployed, individual or networked interaction etc).

'Tool elaboration' can range from minor enhancements to a model that can be carried out on-the-fly, to extensions such as adding a special-purpose notation at the interface, to major re-engineering of the tool.

THE PROJECT TEAM

The project will run for four years. Its PI will be Beynon, the director of the EM research group in Computer Science, but the project itself will be hosted by the existing *Centre for New Technologies Research in Education* (CeNTRE) within WIE. Hammond, the director of the CeNTRE, and Beynon will have overall responsibility for coordinating the educational and CC aspects of the project activity respectively. Three interlinked subprojects will address the opportunities and difficulties that CC presents to the *educational researcher*, to a *teacher*, and to a *learner*. Each will be led by an academic in WIE with the appropriate specialism, with the support of one in CS with CC expertise (1: CA/SR, 2: P&SJ-W/MJ, 3: DW/JS). There will be a doctoral research assistant (DRA) associated with each subproject who will be studying for a doctorate under the joint supervision of the appropriate educational specialist and Beynon. As in normal Warwick practice, there will also be a PhD advisor. In view of the interdisciplinary nature of the research, this role will be played by Hammond and the appropriate CS academic with CC expertise.

The project will be supported by a post-doctoral research fellow (RF) with expertise in CC for learning. It is fortunate and timely that there is as of now a candidate ideally suited for this role: Harfield, currently completing his doctorate on EM for education under Beynon's supervision. The RF will be responsible for consulting with the DRAs to identify issues concerned with context management and tool elaboration. The RF will also be principally responsible for practical CC teaching, website and network support and tool development, and for providing general advice about CC to each subproject. In these supporting roles, the RF will liaise closely with Beynon and other experts in CC where matters of tool design are concerned, and with the educational experts over context management.

To build research capacity, and ensure wider and more critical exposure for CC, members of WIE and CS other than PhD supervisors and advisors, and others in related research centres and departments, will be affiliated to the project. There will also be an external advisory panel, to include experts in education and CS such as Pratt (IoE), Burd (Durham) and Sutinen (Joensuu) with links to the EM group or WIE. Panel members will attend end-of-year events, and act as prototypical external clients or as external examiners.

PROJECT DESIGN AND METHODOLOGY

The project comprises three interlinked subprojects undertaken as PhD studentships in Education. Each will be an in-depth case study carried out in the qualitative research tradition [13]. Each subproject will follow a similar process where the conception, prototyping, construction and 'testing' of empirical models developed using the CC methodology proceeds incrementally in parallel with close consultation between collaborators. The model making activity is unlike software development in "waterfall" or agile models; it more closely resembles 'bricolage' [11c] and is at all times open to engagement from all design participants [14]. There will be close cooperation between the subprojects, and by comparing and contrasting data we shall be able to develop the project as a multiple case study in which depth of understanding of each particular case enables valid generalisation across cases.

Each subproject will take a holistic approach to evaluation but will be viewed through a particular lens – that of an educational researcher, of a teacher (used in a broad sense) and of a learner. Data collection will consist of research diaries of collaborators; interviews with collaborators; observation of work at the screen and screen capture; stimulated recall interviews. CC affords comprehensive histories of model-making interactions with CC tools that can be replayed *as if* to reconstruct situations in such a way that they remain open to live interactive experiment. These will also be available for analysis.

Each subproject will be able to draw on related previous work on EM for learning (year 1), and include one or more substantial focused projects targeting specific users and learning outcomes (years 2-4). All three subprojects will incorporate appropriate comparative studies (year 1), generate technical challenges and requirements to be addressed by the RF (year 1-3), and disseminate via documenting, show-casing and networking (year 3-4). Focused projects for the DRAs will be conceived in year 1, and any major associated CC tool elaboration will be completed by the start of year 2. The RF will work alongside the DRAs in years 2-3, collaborating with the DRAs in empirical studies, making models *for* educational researchers, *with* teachers, and stimulating learners to make their own models. The RF will network widely with external TLRP researchers (years 2-3) with a view to initiating collaborative CC projects that can be sustained beyond the project lifetime; the RF position is funded only for 3 years. In year 3, the RF will work with DRAs to document modes of CC collaboration, case-studies and models. Activities will also include: open workshops at the midpoint and end of the project; induction modules in education and CC for the doctoral students; individual research supervision supported by regular seminars attended by the key project participants; annual end-of-year show-case events for case-studies and associated models.

DRA_1 will consider the perspective of **an educational researcher**, focusing primarily on how CC can support the study of learning (as in the spirit of [15]). Relevant EM archive models expose the "cognitive layers" required to understand activities such as watching sport [3g], or playing noughts-and-crosses [3a]. A suitable focused case-study might explore the potential for using CC as a means to record and document a topical study in child development. Others (for which there already prototypes [1a]) might use CC to generate software to be deployed in diagnosing learning difficulties, probing understanding, or scaffolding learning. Supplementary associated empirical and theoretical studies might explore the relationship between learning and the basic EM concepts of *observables*, *dependencies* and *agents*.

DRA_2 will address the perspective of **a teacher**, investigating the practical implications of CC in blending ongoing development of educational software with teaching, and strategies for delivery and assessment best suited to CC. A useful precedent is an EM environment for teaching relational DBs and exposing the design flaws in SQL [16]. A focused case study might involve the implementation and empirical study of a distributed environment for collaborative use by a teacher and pupils in a classroom environment, and exploit the capacity for auditing interaction in assessment and in generating feedback from the evaluation activity for pupils. Supplementary research might target special needs teaching [17] and the teacher-developer interaction, as well as the ethical implications of the unusually intimate auditing strategies.

DRA_3 will explore CC from the perspective of **a learner**, targeting support for learning-through-building in a constructivist tradition, and the extent to which CC can enhance the quality of the learning experience. This research can draw on the work of the many computer science project students in the EM archive. A focused case study might address participatory design of an interactive environment for health education, resembling an educational game, but with a greater degree of openness and connection with real-world context. This development might be conducted by a hybrid community of developers with quite different levels of technical expertise and specialist domain knowledge. Supplementary research might address the suitability of CC as a vehicle to support different modes, contexts and technologies for learning (cf. [18]).

The intended learning outcome for the targeted researchers, teachers and learners is knowledge of how CC can be of benefit to them, and when and how they can best exploit CC. These LOs will be assessed by whether they regard CC as useful, *can* use it, develop insights through it, and see it as enhancing practice.

OTHER BENEFITS

The project may contribute to a fuller understanding of the science of computing – a subject to which Latour's vision of science as a constructivist activity [6b] most plausibly applies. This has potential implications for CS education at all levels [19]. CC promises to give new force and vitality to the constructivist TEL initiatives, countering the narrow vision of ICT teaching in schools, with its emphasis on the use of standard packages. For more scholarly reference to this claim in its full context, consult [7a].